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Kenneth L. Morgan, Clinton P. Scarborough, Micah D. Gregory, Douglas H. Werner, Ping L. Werner, Scott F. Griffiths

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Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802 USA

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Metasurface with Reconfigurable Reflection Phase for High-Power Microwave Applications

Kenneth L. Morgan, Clinton P. Scarborough, Micah D. Gregory, Douglas H. Werner, and Ping L. Werner
Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802 USA
dhw@psu.edu

Scott F. Griffiths
Joint Non-Lethal Weapons Directorate
Quantico, VA 22134 USA

***Abstract*—We propose a metasurface with reconfigurable reflection phase that can be utilized in high power microwave (HPM) applications. The structure relies on capacitor networks controlled by appropriately biased PIN diodes. Simulations reveal that the metasurface has a reflection phase tuning range of approximately 300 degrees with an associated change in capacitance of 2.7 pF.**

I. Introduction

Recent developments in artificially constructed materials, *i.e.* metamaterials, have provided designers with attractive options for implementation into devices across the electromagnetic spectrum. These sub-wavelength resonating structures are typically characterized by either effective material parameters in 3D structures, or by effective surface impedances for planar structures, called metasurfaces [1]. In addition to exhibiting electromagnetic responses not readily available in natural materials, metamaterials offer the possibility for improved performance in smaller, multi-function applications. Tunable metamaterials further extend the utility of static structures and can alleviate bandwidth limitations and fabrication tolerances [2].

Tunable metasurfaces have been of particular interest in recent years. In some cases they can offer analogous functionality, while occupying less space than their bulk metamaterial counterparts; consequently metasurfaces provide the potential to design devices with less loss. Tunable metasurfaces hold great potential as an analog to reflectarray antennas for beam steering. The mechanism for this operation relies on controlling reflection phase gradients, which can be attained using either electrical or mechanical tuning methods. Each method has its inherent benefits and offers a different set of tradeoffs between various performance considerations, such as cost, reliability, and speed.

Several authors have demonstrated electrically tunable metasurfaces using varactor diodes [3]–[5]. Tuning relies on variable capacitance with reverse bias voltage across the diodes. This method is capable of achieving a flexible and wide tuning range, but it is infeasible for HPM applications as varactor diodes are unable to handle the required high power levels. As an alternative, a few authors have demonstrated mechanically reconfigurable metasurfaces [6], [7]. Although mechanical tuning methods allow operation at high power levels, they suffer from complex fabrication, higher cost, relatively slow speed, and reliability issues. We propose a potential design for a tunable metasurface that benefits from the wide range and speed of electronic tuning, but is capable of operating in high-power systems.

II. Design

The design methodology we propose is based on the tunable high impedance surface proposed by Sievenpiper *et al.* [3]. The printed circuit board structure features a top layer of periodically arranged circular metallic patches above a solid metallic ground plane. The dimensions were chosen such that the size of unit cells are well below one wavelength, where the surface impedance can be defined in terms of lumped circuit parameters, dictated by the unit cell geometry. Shown in Figure 1, the proposed geometry has a unit cell size of $c = 2.5\ cm$, a patch width of $w = 2.4\ cm$, and a patch height over the ground plane of $h = 0.635\ cm$. The respective geometries are selected to optimize for a desired frequency, in this case 1 GHz, as well as to maximize the intrinsic capacitance of the metasurface.

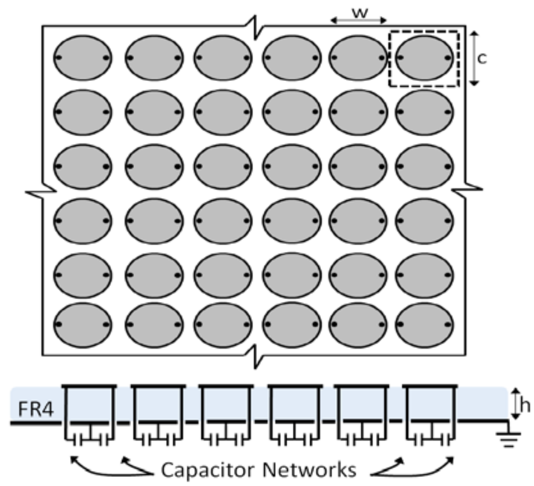

Figure 1 (Top) Schematic of metasurface geometry. (Bottom) Cross section of the metasurface. Vias extend beneath the ground plane. Each capacitor symbol represents a PIN-diode-controlled capacitor network.

Our proposed structure differs from previous work by using PIN diode controlled capacitor networks, rather than varactor diodes, as the tuning mechanism. PIN diodes are typically utilized in radio frequency limiter circuits and are capable of operating at much higher power levels than varactors. Shown below, with the appropriate bias voltage, the total capacitance can be reconfigured with 2^N possible discrete values, where N is the number of capacitors. The PIN diodes effectively act as electrically controlled switches. Alternatively, the capacitor network can rely on miniature relays instead of PIN diodes; however, introducing mechanical components increases reliability concerns.

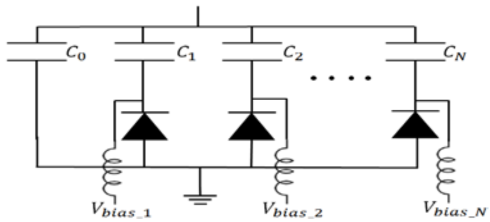

Figure 2 Reconfigurable capacitor network controlled by biased PIN diodes.

This capacitance network should be referred to as “reconfigurable” rather than “tunable.” The discrete capacitance values can only attain 2^N discrete reflection phase values, whereas “tunable” would imply a continuous variation. The network can be expanded and would be limited by space and complexity constraints. Here, the capacitor network is mounted beneath the ground plane and connected to the top layer with vias as shown in Figure 1, rather than mounted directly atop the metallic patches. This provides the flexibility for expanding the capacitance network as needed without the significant space limitations associated with mounting circuit components on the top layer of the metasurface.

III. ANALYSIS

The performance of the proposed design was evaluated using Ansoft High Frequency Structural Simulator (HFSS). The reflection phase can be observed using a single unit cell, as shown by the dotted box in Figure 1. This offset cell fully encloses the capacitor networks for simulation. Periodic boundary conditions were employed on each side of the cell, as well as lumped resistor, inductor, capacitor (RLC) boundary conditions for the capacitor network. Additionally, a standard printed circuit board substrate, FR4, was chosen for insertion between the metallic patches and the ground plane. Figure 3 shows the reflection phase angle as a function of RLC boundary capacitance for a 1 GHz TM excitation at normal incidence. In order to demonstrate the full range of the structure’s tunability, a linear sweep of capacitance values was used rather than the discrete values that would result from the capacitor network.

Figure 3 shows that the metasurface has a reflection phase tuning range of approximately 300 degrees with an associated change in capacitance of 2.7 pF. Typically, diodes capable of operating at high power levels reach minimum capacitance values at about 0.1 pF. Lower values are possible by arranging capacitors in series; however, fabrication tolerances make precise tuning difficult with small values. Further geometrical optimization, however, can alleviate issues with limited capacitance range.

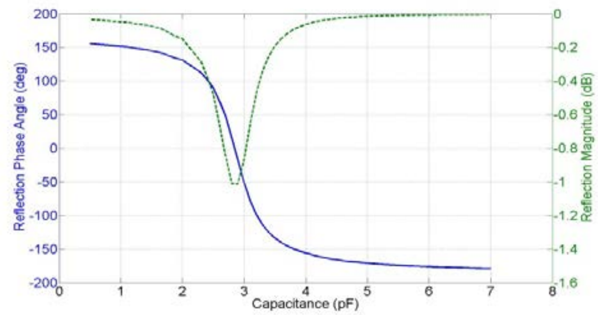

Figure 3 Reflection phase angle (solid) and reflection magnitude (dashed) versus lumped RLC capacitance of metasurface with 1 GHz TM wave at normal incidence.

IV. CONCLUDING REMARKS

An alternative tuning mechanism for metasurfaces in high-power microwave applications has been introduced. Many of the limitations to the design dimensions are largely a function of the desired operational power levels. Ideally, the design should minimize the size of the unit cells and subsequently the power levels that each unit cell experiences. Moving forward the authors intend to further optimize the geometries of the design to extend the capacitance range and demonstrate a reconfigurable HPM metasurface-enabled reflector.

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